Pinniped Hearing in Complex Acoustic Environments

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LONG-TERM GOALS

Pinnipeds (seals, sea lions, and walruses) are amphibious marine mammals that are susceptible to coastal anthropogenic noise. The long-term goals of this effort are to improve understanding of 1) the sound detection capabilities of several pinniped species, and 2) the effects of noise exposure on the sound detection capabilities of these species. The research will show how amphibious mammals receive and perceive acoustic information in background noise.

OBJECTIVES

Improve understanding of hearing in pinnipeds by extending psychoacoustic profiles of sound reception obtained from simplified auditory processing tasks to those describing performance under increasingly complex acoustic conditions. Relate laboratory measurements to concurrent field studies of communication in fluctuating natural noise backgrounds. Strengthen predictive models that describe how signal structure and noise environments interact to constrain auditory performance, and develop weighting functions that can be used for species-typical acoustic risk assessments.

APPROACH

Psychoacoustic measurements of hearing are obtained from California sea lions, harbor seals, and northern elephant seals under highly controlled laboratory conditions. Long-term captive subjects are trained using operant conditioning procedures to report the presence or absence of auditory signals in noisy or quiet backgrounds. Testing takes place both under water (in a mapped, reverberant acoustic field) and in air (in a sound-attenuating hemi-anechoic chamber) because the sensitivity and frequency range of hearing in pinnipeds varies significantly as a function of medium (Fig. 1). The stimuli presented during testing comprise synthetic and natural sounds that are systematically varied in spectral complexity, or in referential meaning established through explicit associative learning paradigms. The general approach is to obtain absolute detection thresholds for these complex sounds and compare these thresholds to those previously obtained for pure-tone signals. The tasks are then repeated against a variety of synthetic and natural background masking stimuli to determine the signal-

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to-noise ratios that limit auditory detection, and in some cases, auditory recognition. The methods are modeled in part from studies of bird communication in noise (Dooling et al., 2009; Lohr et al., 2003).

In addition to using psychoacoustic methods to assess auditory thresholds under varying signal and noise conditions, the metric of reaction time as a proxy for perceptual loudness measurements is investigated by measuring response latency while varying both signal frequency and signal level. The resultant latency-intensity functions are used to develop equal latency contours. Equal latency countours should approximate equal loudness countours across the frequency range of hearing (Moody, 1970), and thus may be used to determine auditory weighting functions for pinnipeds.

Field measurements of representative species-typical vocalizations and associated ambient noise are made at pinniped breeding rookeries (Fig. 2), and simple propagation models of natural signals through representative environments are generated. The data collected include measurements of environmental noise (maximum and equivalent continuous sound pressure level over different time scales), vocalization parameters (source level, spectral composition, call duration, intercall interval), and information about individuals (age, sex, identity, size, reproductive state, and dominance status). Collectively, the complementary laboratory and field studies allow effective detection and recognition ranges for biologically relevant sounds to be modeled under various conditions of natural and anthropogenic noise.

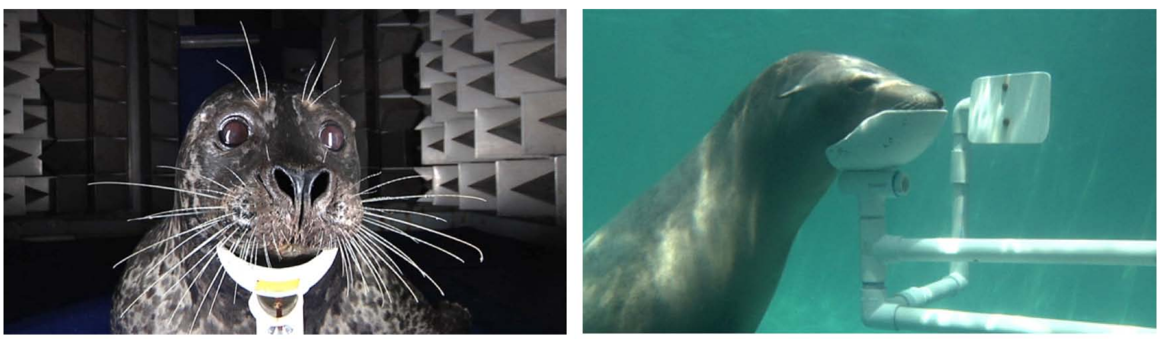

Figure 1. (left) A trained harbor seal performing an auditory detection task in the aerial testing chamber. (right) A trained California sea lion performing an auditory detection task in the underwater testing pool.

Figure 2. (left) Coastal ambient noise measurements obtained at pinniped rookery. (right) Vocal emissions from adult male northern elephant seal A33 recorded at a distance of 1 m.

Key personnel in the laboratory in FY2010 included the PI, UC Santa Cruz graduate students Asila Ghoul (Ocean Sciences) and Peter Cook (Psychology), and marine mammal trainers Amy Bernard (through 5/2010) and Caroline Casey (from 5/2010). The field data were collected by the PI, Caroline Casey, and Dr. Brandon Southall, a collaborator from SEA, Inc. who is also a UC Santa Cruz Research Associate. The research program is supported by a small group of undergraduate and post-graduate volunteers and interns. Dr. Ronald Schusterman, long-time project PI and consulting Researcher, passed away in 2/2010.

WORK COMPLETED

In FY2010, significant accomplishments included (1) development of technical resources for new and planned experiments, (2) expansion of marine mammal resources, (3) continuation of audiometric monitoring efforts on trained subjects, (4) progress on psychoacoustic equal latency study, and (5) progress on bioacoustic field study of communication in noise.

Hardware and software used for acoustic calibration, mapping, and response measurement were reconfigured, improved, or replaced to support planned psychoacoustic experiments using complex stimuli with partial external support from James Finneran (Space and Naval Warfare Systems Center Pacific, Biosciences Division) and Christian Brandt (University of Southern Denmark, Insitute of Biology, Center for Sound Communication).

A 2-year-old female California sea lion (NOA0006602) was added to the permanent group of research animals housed in the laboratory and completed training for participation in acoustic signal detection procedures. An evoked potential hearing screening procedure was conducted with this animal in 4/2010 to confirm normal auditory function. The other resident research animals, including a 25-year-old California sea lion, a 22-year-old harbor seal, and a 17-year-old northern elephant seal, participated in ongoing hearing testing as part of the monitoring effort for changes in hearing sensitivity as a result of experimental noise exposure and natural aging.

The study of response latency as a proxy for loudness perception was initiated with three animals. All subjects were trained to depress an electronic switch and to release it immediately upon detection of an auditory stimulus. Repeated-measures testing for each animal will be completed at a minimum of 7 stimulus levels referenced to best sensitivity at each of 7 testing frequencies. Latency-intensity functions have thus far been completed at 4 frequencies for the California sea lion, 3 frequencies for the harbor seal, and 1 frequency for the northern elephant seal, and will be used to develop equal latency contours for each subject across the frequency range of hearing.

Field studies of elephant seal communication in natural noise were conducted 1/2010 - 2/2010 at Año Nuevo State Park in San Mateo County, California during the breeding season. Data were obtained over 24 days and added to the long-term acoustic database. More than 70 ambient noise measurements were conducted coincident with recordings of vocal behavior. Research effort in 2010 was directed on calls emitted by sub-adult and adult males. A total of 73 males were marked and photographed for subsequent size determination. Of these, 20 were recorded at known distances with over 10 complete calling bouts per individual (range 10-67 bouts). Dyadic behavioral interactions between marked individuals were scored for dominance ranking determined by ELO ratings. Acoustical, behavioral, photometric, and environmental noise data were compiled for analysis of factors influencing call level and structure. Propagation characteristics of calls through the environment were empirically determined.

RESULTS

The technical resources developed in 2010 will support the planned psychoacoustic studies of hearing in progressively realistic scenarios scheduled to begin in early 2011. Baseline monitoring of hearing in research subjects indicates sensitive and stable hearing thresholds across most of the frequency range of hearing in the harbor seal and the northern elephant seal. The harbor seal does exhibit a residual 8 dB noise induced hearing loss at 5.8 kHz following exposure to tonal fatiguing noise in 2008; this is being carefully monitored for long-term recovery. The older California sea lion shows general presbycusis, which is being monitored as part of a long-term study of aging effects on hearing. The addition of a young California sea lion trained for participation in signal detection procedures will ensure that representative data for this species is obtained in future studies.

The latency-intensity functions being measured for each subject at each of several frequencies appear promising for the estimation of equal loudness functions based on reaction time metrics. The data obtained in air thus far for the California sea lion and harbor seal are reliably fit by non-linear regression analysis using a power function (as shown in Fig. 3); this relationship is used to extrapolate sound pressure levels corresponding to discrete latency values for each subject that will be pooled to generate equal latency contours across the frequency range of hearing. The data are highly reliable across frequencies for the California sea lion and harbor seal ($p<.05$), but confounded in the northern elephant seal due to non-auditory testing variables. The equal latency countours to be provided for the California sea lion and harbor seal should predict species-specific weighting functions that can be used for mitigation and regulatory purposes.

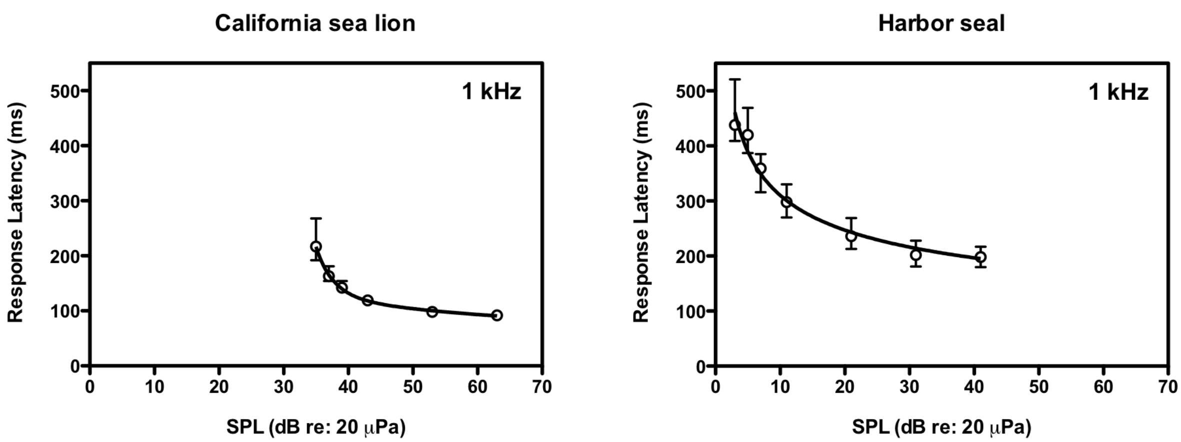

Figure 3. (left) Representative latency-intensity function for a California sea lion to 500 ms pure tones of 1 kHz. Error bars indicate response variability (25% and 75% quartile ranges based on 50 trials per data point). Note that both reaction times and response variability decrease with increasing sound pressure level. (right) The same data shown for a harbor seal.

The highlights from the 2010 field study of communication in noise include the measurement and characterization of the airborne vocal signals emitted by sub-adult and adult males during the breeding season in varying conditions of environmental noise and biological noise. The source levels of these calls were extremely loud and varied across individuals. Mean call levels measured at 1m ranged from 108.4-113.1 dB_{RMS} re: 20 µPa and 121.4-128.3 dB_{peak} re: 20 µPa. Ambient noise measurements were

highly dependent on both social conditions in breeding rookeries and environmental conditions (primarily surf noise). When seal vocalizations were the dominant contributor to background noise, mean ambient noise levels (1 minute Leq levels) in variable rookery activity conditions were 74.7 dB re: 20 µPa ("low" activity), 79.4 dB re: 20 µPa ("moderate" activity), and 80.7 dB re: 20 µPa ("high" activity). In conditions where high surf activity was the primary source of background noise, mean ambient noise levels (1 min. Leq levels) were 90.2 dB re: 20 µPa.

Analysis of the spectral content of these calls from identified individuals (combined with temporal data, photometric data, and dominance ranking analysis) will serve as the basis of a planned 2011 collaboration that will use playback methodologies to determine the information content of these calls and likelihood of informational masking by natural noise. The collaborators on this effort are Nicolas Mathevon from the Universite de Saint-Etienne (Laboratory of Neuroethology) and Isabelle Charrier from the Université Paris Sud (Center for Neurosciences).

Propagation analyses of calls emitted by both adult males and adult females indicate that transmission loss of signal amplitude on the rookery can be adequately modeled using an equation of the form 15 log R, which is intermediate to the transmission loss predicted by spherical and cylindrical spreading.

IMPACT/APPLICATIONS

The audiometric data generated by this project and preceding projects have contribute to noise exposure criteria developed specifically for free-ranging marine mammals, which in turn are used by the operational Navy, industry, and U.S. and International regulators to establish appropriate guidelines and mitigation for anthropogenic noise emissions in marine environments.

RELATED PROJECTS

An Opportunistic Study of Hearing in Sea Otters (Enhydra lutris): Measurement of Auditory Detection Thresholds for Tonal and Industry Sounds. C. Reichmuth (UC Santa Cruz) is the PI; the project is supported by Minerals Management Service. This project expands upon auditory research with pinnipeds by examining hearing in another marine carnivore, the sea otter. There is overlap in facilities, experimental resources, and personnel.

Airgun Effects on Arctic Seals: Auditory Detection, Masking, and Temporary Threshold Shift. C. Reichmuth (UC Santa Cruz) is the PI; the project is supported by the Joint Industry Programme on Sound and Marine Life. This project expands upon auditory research with pinnipeds by examining hearing and the effects of noise in arctic seals. There is overlap in facilities, experimental resources, and personnel.

Detection and Tracking of Submerged Hydrodynamic Wakes Using a Bioinspired Hybrid Fluid Motion Sensor Array. J. Humphrey (Univeristy of Virginia) is the PI; the project is supported by the Office of Naval Research. Field testing of sensor design is conducted at Long Marine Laboratory with one of the seals involved in the current project.

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